



Crack Turning Mechanics of Composite Wing Skin Panels

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July 20, 2001

Final Report
Period: January 1, 1998 – April 30, 2001
NASA Grant: NAG-1-1981

Prepared for

Mechanics and Durability Branch
NASA Langley Research Center
Hampton, VA 23681-0001

Technical Monitor: Dr. James R. Reeder

Research Summary

The safety of future composite wing skin integral stiffener panels requires a full understanding of failure mechanisms of these damage tolerance critical structures under both in-plane and bending loads. Of primary interest is to derive mathematical models using fracture mechanics in anisotropic cracked plate structures, to assess the crack turning mechanisms, and thereby to enhance the residual strength in the integral stiffener composite structures. The use of fracture mechanics to assess the failure behavior in a cracked structure requires the identification of critical fracture parameters which govern the severity of stress and deformation field ahead of the flaw, and which can be evaluated using information obtained from the flaw tip.

In the three-year grant, the crack-tip fields under plane deformation, crack-tip fields for anisotropic plates and anisotropic shells have been obtained. In addition, methods for determining the stress intensity factors, energy release rate, and the T-stresses have been proposed and verified. The research accomplishments can be summarized as follows:

- (1) Under plane deformation in anisotropic solids, the asymptotic crack-tip fields have been obtained using Stroh formalism;
- (2) The T-stress and the coefficient of the second term for σ_y , g_{32} , have been obtained using path-independent integral, the J-integral and Betti's reciprocal theorem together with auxiliary fields;
- (3) With experimental data performed by NASA, analyses indicated that the mode-I critical stress intensity factor K_{Ic} provides a satisfactory characterization of fracture initiation for a given laminate thickness, provided the failure is fiber-dominated and crack extends in a self-similar manner;
- (4) The high constraint specimens, especially for CT specimens, due to large T-stress and large magnitude of negative g_{32} term may be expected to inhibit the crack extension in the same plane and promote crack turning;
- (5) Crack turning out of crack plane in generally anisotropic solids under plane deformation has been studied. The explicit expressions of the stress intensity factors, T-stresses, and energy release rate at the kinked tip are presented in terms of nondimensional coefficients together with the stress intensity factors, T-stresses acting on the main crack tip prior to turning;
- (6) The role of T-stress and the higher-order term of σ_y on the crack turning and stability of the kinked crack has been quantified. The effect of T-stress, parameterized by β , on the stress intensity factors and energy release rate at the kinked crack tip has been illustrated;
- (7) Asymptotic crack-tip fields including the effect of transverse shear deformation (Reissner plate theory) in an anisotropic plate under bending, twisting moments, and transverse shear loads has been presented;

- (8) The expression of the path-independent J-integral in terms of the generalized stress and strain has been derived. The energy release rate can be expressed in a compact form in terms of bending stress intensity factors and Barnett-Lothe tensor L ;
- (9) Asymptotic crack-tip fields including the effect of transverse shear deformation (Reissner shallow shell theory) in a general anisotropic shell has been developed. This topic is an extension of the work for crack-tip fields in anisotropic plates. Due to the curvature, the membrane and bending deformation are coupled, so are the stress intensity factors. It was verified that, up to the second order of the crack-tip fields in anisotropic shells, the governing equations for bending, transverse shear and membrane deformation are mutually decoupled;
- (10) The Stroh formalism was used to characterize the crack tip fields in shells up to the second term and the energy release rate was expressed in a very compact form. The proposed method was verified by three numerical examples of two circular cylindrical panels and a circular cylinder.

Publications resulting from this grant

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2. F. G. Yuan and S. Yang, "Asymptotic Crack-tip Fields in an Anisotropic Plate subjected to Bending, Twisting Moments and Transverse Shear Loads", *Composites Science and Technology*, December, Vol. 60, pp. 2489-2502, 2000.
3. F. G. Yuan and S. Yang, "Kinked Crack in Anisotropic Bodies", *International Journal of Solids and Structures*, Vol. 37, pp. 6635-6682, 2000.
4. F. G. Yuan and S. Yang, "Fracture Behavior of Stitched Warp-knit Fabric Composites" *International Journal of Fracture*, Vol. 108, pp. 73-84, 2001.
5. F. G. Yuan and S. Yang, "The Determination and Representation of the Stress Coefficient Terms by Path-Independent Integrals in Anisotropic Cracked Solids", *International Journal of Fracture*, Vol. 101, pp. 291-319, 2000.
6. C. C. Poe, Jr., J. R. Reeder, and F. G. Yuan, "Fracture Behavior of a Stitched Warp-Knit Carbon Fabric Composite", *NASA/TM-2001-210868*, 2001.
7. F. G. Yuan, "Determination of Stress Coefficient Terms in Cracked Solids for Monoclinic Materials with Plane Symmetry at $x_3 = 0$ ", *NACA/CR-1998-208729*, 1998.
8. C. Lane and F. G. Yuan, "Three-dimensional Analysis of Fracture Parameters of Composite Stiffened Panels", 41st AIAA/ASME/ASCE/AHS/ASC SDM Conference, Atlanta, April, 2000.

9. G. Cai and F. G. Yuan, "Fracture Parameter Evaluation of Composite Panels under In-plane Loading", 41st AIAA/ASME/ASCE/AHS/ASC SDM Conference, Atlanta, April, 2000.
10. F. Liang and F. G. Yuan, "Two-Parameter Characterization of Crack Tip Fields in an Anisotropic Plate under Bending", 12th *International Conference on Composite Materials*, Paris, France, July, 1999.
11. F. G. Yuan and S. Yang, "Kinked Crack in Anisotropic Bodies under In-Plane Deformation", 40th AIAA/ASME/ASCE/AHS/ASC SDM Conference, St. Louis, MO, April, 1999.
12. F. Liang and F. G. Yuan, "Determination of Stress Intensity Factor and T-stress in an Anisotropic Plate", 40th AIAA/ASME/ASCE/AHS/ASC SDM Conference, St. Louis, MO, April, 1999.
13. F. G. Yuan and F. Liang, "Fracture Behavior of Stitched Warp-knit Fabric Composites", 98 ICES Meeting, Atlanta, October, 1998.
14. F. G. Yuan and S. Yang, "Asymptotic Crack-tip Fields in an Anisotropic Plate subjected to Bending Moments and Transverse Shear Loads", Presented in the ASME Winter Meeting, Anaheim, CA, November, 1998.
15. F. G. Yuan and S. Yang, "The Application of Fracture Mechanics to Stitched Warp-knit Fabric Composites", 39th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, April 20-23, 1998, Long Beach, CA.